

Fertilizer Recommendation: Correlation and Calibration Study of Soil P Test for Yard Long Bean (*Vigna unguilata* L.) on Ultisols in Nanggung-Bogor

Anas Dinurrohman Susila^{1*}, Juang Gema Kartika¹, Tisna Prasetyo¹, and Manuel Celiz Palada²

¹Department of Agronomy and Horticulture, Faculty of Agriculture, Bogor Agricultural University, Jl. Meranti Kampus IPB Darmaga 16680, Indonesia

²Crop and Ecosystems Management Unit, AVRDC-World Vegetable Center, P.O. BOX, Shanhua, Tainan 74199, Taiwan

Received 14 Mei 2010/Accepted 8 July 2010

ABSTRACT

Yard long bean (*Vigna unguilata* L.) 777 was grown in Ultisols, which typically have low pH and high P-fixation, to determine the best correlation of soil extraction methods for soil P with yields, and to develop soil P response categories. The research was conducted at SANREM base camp in Hambaro Village, Nanggung, Bogor, Indonesia from April to August 2008. Treatments were arranged in a Split Plot Design with three replications. The main plots were treatments with soil P status of 0X, $\frac{1}{4}$ X, $\frac{1}{2}$ X, $\frac{3}{4}$ X and X, where is X = 1,590.5 kg SP-36 ha⁻¹ (36% P₂O₅) applied once a month before planting. The subplots were P application rate of 0, 75, 150, 225 and 300 kg P₂O₅ ha⁻¹. Yard long beans were planted in double rows per bed, 60 cm between rows and 25 cm within rows, 2 seeds per hole, with plot size of 1.5 m x 5 m. Coefficient correlation (r) of extraction reagents Olsen, Bray-1, HCl 25%, and Mechlich-1 were 0.772, 0.765, 0.755, and 0.732, respectively. Based on Olsen soil testing methods, soil response categories of very low, low, medium, and high were (ppm P₂O₅) ≤ 18.40, 18.40 < P < 117.27, 117.27 < P < 267.04, and ≥ 267.04 extracted-P, respectively. Based on Bray-1 soil testing methods, soil response categories for low, medium, and high were ≤ 87.81, 87.81 < P < 233.78, and ≥ 233.78 extracted-P (ppm P₂O₅), respectively. Fertilizer recommendation based on the Olsen soil test for low response category was 185.75 kg P₂O₅ ha⁻¹, and for the medium soil category was 175.97 kg P₂O₅ ha⁻¹. The Bray-1 soil test for the low response category was 184.31 kg P₂O₅ ha⁻¹, and for the medium soil category was 161.39 kg P₂O₅ ha⁻¹.

Keywords: calibration, fertilizer recommendation, phosphorus, yard long bean

INTRODUCTION

Soil testing using a single-nutrient soil analysis in Indonesia has been developing since 1970. However, due to limited research funds, soil testing has not been programmed continuously and recommendation of location specific fertilization based on soil family has also not yet been established (Al-Jabri, 2007). Correlation studies for soil P testing have been conducted for rice (Nursyamsi *et al.*, 1993) and corn (Kasno *et al.*, 2001), however it has not been conducted for horticultural crop especially for vegetable crops.

The basic purpose of soil fertility evaluation is to provide information on the nutrient status of the soil and to predict the relative responses to the added nutrients. The Crop Nutrient Requirement (CNR) value is the amount of various nutrients needed to produce optimum, economical yields from a fertilization standpoint. It is important to remember that these nutrient amounts are supplied to the crop from both soil and fertilizer application. Phosphorus (P) fertilizer will only be applied when a properly calibrated

soil test indicates very small extractable amounts of this nutrient in the soil.

The nutrient status of cultivated soils varies and is continually changing due to the influence of fertilizer addition, nutrient losses by leaching or removal, and overall management. Site-specific estimation of the nutrient fertility status of soil are, therefore, very important for rational fertilizer use. Reliable site-specific information can only be accomplished through an orderly program of soil fertility evaluation in which proper attention is given to the following: 1) Techniques of soil sampling; 2) methods of soil analysis; 3) systems for correlating soil analysis results and crop responses; 4) model for interpretation of fertilizer response in field trials, and 5) procedure for preparing economically sound fertilizer recommendation.

Phosphorus is an essential component for many physiological processes related to proper energy utilization in plants. Phosphorus is used in several energy transfer compounds in the plants. A very important function of P is as an important element of nucleic acids, the building blocks for the genetic code material in plant cells. Plants derive their P needs from soil, and uptake P mostly in the orthophosphate form. Native soil P levels are often low enough to limit crop production. Both inorganic P

* Corresponding author. e-mail: anasdsusila@yahoo.com

fertilizers (treated rock phosphate) and organic P sources (animal manures) are equally adequate at supplying the orthophosphate ion and correcting P deficiencies in soil (Daniels *et al.*, 2008; Hochmuth, 2008).

Phosphorus fertilization is a key component in increasing soil productivity and in maximizing yield of crops. However, inputs of fertilizer and manure in excess of crop requirements might lead to a build-up of soil P levels and increased P runoff from agricultural soils. Phosphorus loss in runoff from agricultural fields has been identified as an important contributor to eutrophication (Dobermann *et al.*, 2002; Daverede *et al.*, 2003).

Soil P tests are fundamental analytical tools for assessing the P nutrient status of the soil. Normally, the plants can utilize only a small percentage of the total soil P, such a quantity being strictly correlated to the labile soil P (portion of P relatively loosely bound to the soil colloids). Soil test P is not an indication of total P in the soil but of how much is available for plant use. Soil testing is the key component for determining the need for P fertilization. Also, if fertilization is required, soil test results guide the rate of application recommended to optimize production (Sawyer and Mallarino, 1999; Dobermann *et al.*, 2002; Daniels *et al.*, 2008).

Soil extracting reagents like Mechlich-1, Olsen, Bray-1, Morgan Vanema, HCl 25%, Water, Truog, and other extracting reagent have been used in correlation and calibration study of soil analysis and crop response of P in many research project. This is an important consideration as there have been many methods developed to test soils for crop available P. Each can have a widely different interpretation index (Sawyer and Mallarino, 1999). Kidder *et al.* (2003) used Mechlich-1 to interpret P requirement for environmental horticulture, and divided soil P status into 5 levels: very low (P < 10 ppm), low (P 10-15 ppm), medium (P 16-30 ppm), high (P 31-60 ppm) and very high (P > 60 ppm).

Kelling *et al.* (1998) described several factor affecting P recommendations, i.e. crop demand level (each crops requires varying level of available P to optimize yield), subsoil fertility (based on the subsoil nutrient supplying power of the soil), the yield potential of the soil and the farmers yield goals. Chang *et al.* (2004) reported that the best approaches for minimizing recommendation errors were nutrient specific. Phosphorus recommendations were improved using multiple years of yield monitor data to develop landscape-specific yield goals, sampling old homesteads separately from the rest of the field, and P recommendations. The objective of this study was to build environmentally friendly fertilizer recommendations based on soil analysis for vegetable production in Ultisols. Specific objectives of this study were to find out the best soil P extraction methods and response categories of soil-P on yield of yard long bean.

MATERIALS AND METHODS

The research was conducted at SANREM base camp in Hambaro Village, Nanggung, Bogor, Indonesia from April to August 2008. The soils at the location are Ultisols, which typically have low pH and high P-fixation by aluminum. Treatments were arranged in a Split Plot Design with three replications. The main plot treatment was soil P status and the subplot was P rate. Soil P status was developed by application of P at the rates of 0, 45, 90, 135 and 180 kg P₂O₅ ha⁻¹ from December 2006 to April 2007 for vegetables production, followed by application of 0X, ¼X, ½X, ¾X and X, where X = 1,590.5 kg SP-36 ha⁻¹ (36% P₂O₅) one month before planting. The subplot treatments were P rates of 0, 75, 150, 225 and 300 kg P₂O₅ ha⁻¹ applied as pre-plant applications. Yard long beans, variety 777, were sown in double rows per bed, 60 cm between rows and 25 cm within rows, 2 seed per hole. The total plot number was 25 times 3 replications which is equal to 75 plots with individual plot size of 1.5 m x 5 m.

Lime (CaCO₃) was well incorporated (1 ton ha⁻¹) into the beds two weeks before planting. Furrow irrigation was carried out at one-week intervals and weeding was performed when necessary. Fertilizer rates for N and K were 135 kg K₂O ha⁻¹ and 100 kg N ha⁻¹, respectively. Phosphorus rates were applied based on treatment. Fifty percent of N and K were applied pre-plant and the remaining applied in two side dressings of 25 % each at 3 and 6 weeks after transplanting. First pod harvesting was carried out at seven weeks after planting, every 3-4 days. Soil samples for the correlation test were taken two days before planting or 4 weeks after P status treatments were applied. Phosphorus soil extracting reagents that had been evaluated were Bray-1 (HCl 0.025 N + NH₄F 0.03 N), Truog [H₂SO₄ 0.002 N + (NH₄)₂SO₄; pH 3], Olsen (NaHCO₃ 0.50 N; pH 8.5), HCl 25%, Water, Mechlich-1 (HCl 0.05 N and H₂SO₄ 0.025 N), Morgan Vanema (NH₄-OAc 1 M; pH 4.8) .

Measurement on plant height and plant diameter were conducted at 2, 3 and 4 weeks after transplanting. Pod weight per plot and marketable yield per plot were measured at 7 weeks after transplanting. Analysis of variance of data was calculated using SAS 8.12 (SAS Institute, N.C). A correlation test was used to find out the best soil P extracting reagent for yard long bean in acid soil (Ultisols). Determination of soil P-response categories was conducted based on the best crop response to soil P-extracting reagents. The soil P response was divided into four categories; very low if relative yield (RY) < 50%, low RY 50-75%, medium RY 75-100%, and high RY = 100%. The critical border to determine P soil index for each group is shown in the calibration curve correlating P soil index (X) and relative yield (Y). An orthogonal polynomial test was used to find out the optimum fertilizer rate of P for maximum yield for each soil response category.

RESULTS AND DISCUSSION

Plant Growth and Yield

The effect of soil P status on plant height and stem diameter was not significant except on plant height at 2 weeks after planting. Application of P fertilizer to build up soil P status from 0 to X = 1,590.5 kg SP-36 ha⁻¹ (36% P₂O₅) increased linearly for plant height from 2 weeks after planting (Table 1). The same response was obtained on marketable yield per plot (Table 2). Soil P status from 0 to 1,591 g SP-36 ha⁻¹ increased marketable yield per plot linearly from 2,167.4 to 2,920.6 g plot⁻¹. However, there was no significant effect on non-marketable yield per plot and pod length. These results indicated that the range of soil P status in the research site was wide enough to build a correlation study between soil P status and yield response of yard long bean.

Correlation between Soil Extracted-P and Yield

Five different soil-P extraction methods resulted in different soil-P indices. The strongest extracting reagents to

the weakest were HCl 25% (521–1,565 ppm P₂O₅) followed by Mechlich-1 (30–841 ppm P₂O₅), Truog (13–489 ppm P₂O₅), Olsen (43–417 ppm P₂O₅), Bray-1 (23–414 ppm P₂O₅), Morgan Vanema (1–18 ppm P₂O₅), and water (0.1–1.6 ppm P₂O₅). Extracted-P by different extraction methods on different P-application rates on Ultisols is presented in Table 3. The strongest extraction methods was not necessarily be the best solution for soil P extraction. The ideal soil test has the following characteristics: 1) the extracting reagent is effective for most, if not all plant mineral nutrients, and for all soil types, 2) the procedure accurately measures the plant-availability of the nutrient, and 3) the test is simple, inexpensive, quick, reproducible, and sensitive to all soil factors controlling nutrient availability (Skogley, 1994).

In order for a soil test to be useful, there must be a positive correlation between the index and the crop response (yield). The best extraction method will mimic how the plant root extracts P from the soil, therefore it will have good correlation with plant yield. The highest coefficient correlation to the lowest was Olsen (0.772), Bray-1 (0.765), HCl 25% (0.755), Mechlich-1 (0.732), Morgan Vanema (0.650), Water (0.623), and Truog (0.266) (Table 4). For an extracting reagent to be effective, it requires that a low index

Table 1. The effect of soil P status on plant height and stem diameter of yard long bean at 2, 3, and 4 weeks after planting

Soil P status by application of SP-36 (kg ha ⁻¹)	Plant height (weeks after planting)			Stem diameter (weeks after planting)		
	2	3	4	2	3	4
	cm			cm		
0 (0X)	17.54b	42.67	123.68	0.317	0.413	0.485
398 (1/4X)	18.88a	51.54	140.57	0.364	0.440	0.498
795 (1/2X)	18.58a	48.64	135.13	0.387	0.449	0.505
1193 (3/4X)	19.28a	49.01	135.91	0.349	0.459	0.534
1591 (X)	19.53a	53.47	139.88	0.411	0.467	0.524
Response	L**	NS	NS	NS	NS	NS

Note: * = Significant at 5% F test; ** = significant on 1% F test; NS = Not Significant; L = Linear

Table 2. The effect of soil P status on marketable yield, non-marketable yield and pod length of yard long bean

Soil P status by application of SP-36 (kg ha ⁻¹)	Marketable yield per plot	Non-marketable yield per plot	Pod length
	g	g	cm
0 (0X)	2167.4 b	372.68	56.09
398 (1/4X)	2614.2 ab	474.40	57.75
795 (1/2X)	2816.4 ab	435.18	58.33
1193 (3/4X)	3058.0 a	515.61	57.73
1591 (X)	2920.6 ab	485.91	58.82
Response	L*	NS	NS

Note: * = Significant on 5% F test; NS = Not Significant; L = Linear

be related to reduced growth responses for a crop grown on that soil, and conversely, a high index be related to maximum crops response (Dahnke and Olson, 1990). Soil-P extraction methods with coefficient correlation > 0.7 (Olsen, Bray-1, HCL 25%, Mechlich-1) can be recommended to test soil P for yard long bean in Ultisols Nanggung, Bogor. However, evaluation of the operational cost and reproducibility of that extraction reagent is still needed.

Calibration of the Soil P Test

Once a good correlation between indices produced by the extracting reagent and crop response is established, soil test indices are usually grouped into response categories so

that the indices can be interpreted and become meaningful. By plotting of percent relative yields and corresponding extracted-P, it can be determined plant response categories of that soil. Yard long bean relative yield plotted against extracted-P by Olsen reagent is presented in Figure 1. Extracted-P concentration ≤ 18.40 ppm resulted in $\leq 50\%$ crop relative yield and therefore was termed "very low". A "low" response category result of 50% to 75% of relative yield was obtained where soil extracted-P was > 18.40 to < 117.27 ppm. A "medium" response category result of 75% to 100% of relative yield was obtained where soil extracted-P was > 117.27 to < 267.04 ppm, while a "high" response category result of $\geq 100\%$ of relative yield was obtained for soil extracted-P ≥ 267.04 ppm.

Table 3. Extracted-P by various extraction methods from different P fertilizer rates on Ultisols, Nanggung, Bogor

Soil P status by application of SP-36 (kg ha ⁻¹)	Truog	Mechlich-1	HCl 25%	Olsen	Bray 1 (P ₂ O ₅ ppm)	Water	Morgan Vanema
----- Extracted-P -----							
0 (0X)	54 ± 35.55	51 ± 27.59	613 ± 114.18	62 ± 17.35	34 ± 1290	0.2 ± 0.10	2 ± 0.00
397,625 (1/4X)	58 ± 54.22	94 ± 29.57	704 ± 129.00	118 ± 100	60 ± 16.65	0.13 ± 0.06	2.3 ± 1.53
795,250 (1/2X)	77 ± 61.29	182 ± 91.76	742 ± 165.77	126 ± 43.41	108 ± 60.78	0.33 ± 0.23	5.3 ± 3.06
1,192,875 (3/4X)	314 ± 151.84	487 ± 309.02	1317 ± 303.04	324 ± 95.04	263 ± 132.22	0.37 ± 0.15	10.7 ± 6.66

Table 4. Correlation between extracted-P by different extraction reagents with yard long bean relative yield on Ultisols, Nanggung, Bogor

Extraction reagent	Linear equation	Coefficient correlation
Truog	RY= 70.563 + 0.064 P	0.566
Mechlich-1	RY= 66.673 + 0.052 P	0.732
HCl 25%	RY= 47.280 + 0.034 P	0.755
Olsen	RY= 61.548 + 0.097 P	0.772
Bray-1	RY= 64.248 + 0.108 P	0.765
Water	RY= 67.724 + 32.239 P	0.623
Morgan Vanema	RY= 66.465 + 2.239 P	0.650

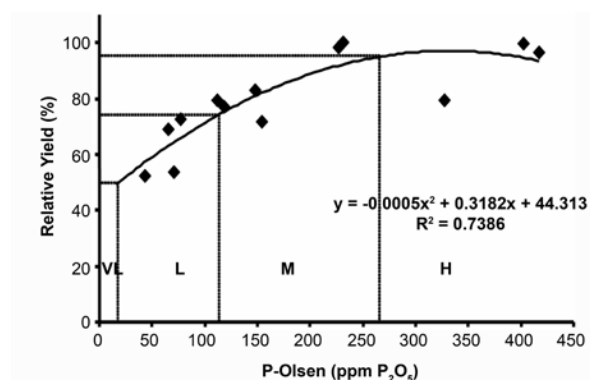


Figure 1. Plot of relative yield and corresponding extracted-P using Olsen extraction method in Ultisols, Nanggung, Bogor. VL = Very Low, L = Low, M = Medium, H = High

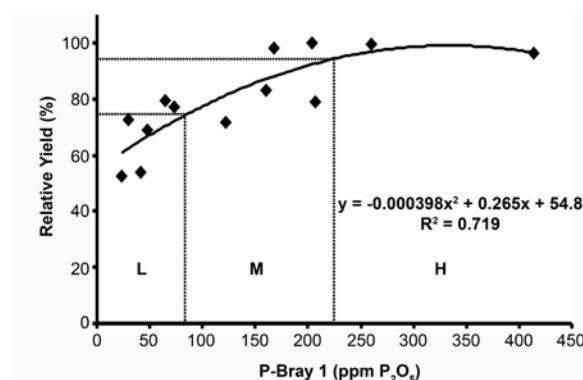


Figure 2. Plot of relative yield and corresponding extracted-P using Bray-1 extraction method in Ultisols, Nanggung, Bogor. VL = Very Low, L = Low, M = Medium, H = High

Plots of extracted-P by Bray-1 reagent with yard long bean relative yield can be seen in Figure 2. There was no “very low” response category obtained by Bray-1 soil P test from this study. A “low” response category result ($\leq 75\%$ of relative yield) was obtained with soil extracted-P ≤ 87.81 ppm, a “medium” response category result (75 % to 100 % relative yield) was obtained with soil extracted-P between < 87.81 to < 233.78 ppm, while a “high” response category result of $\geq 100\%$ of relative yield was obtained with soil extracted-P ≥ 233.78 ppm. The Olsen and Bray-1 soil test calibration for yard long bean in Ultisols, Nanggung, Bogor can be seen in Table 5.

Fertilizer Recommendation

The objectives of grouping soil test indices into responses categories are to recommend the quantity of fertilizer required for those sites to produce maximum yield. The relationship between P-fertilizer rate and relative yield of yard long bean on Ultisols, Nanggung, Bogor, based on response category determined by different extraction methods, can be seen in Figure 3. Based on Olsen extraction methods, under “low” soil response category the regression equation was $RY = -0.00065x^2 + 0.24147x + 62.89249$, $R^2 = 0.26677$

$= 0.26677$. From this regression model, optimum predicted P-fertilizer rate was $185.75 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$ or equal to $515.96 \text{ kg SP-36 ha}^{-1}$ (36% P_2O_5). Under “medium” soil response category the regression equation was $RY = -0.00068x^2 + 0.23796x + 52.22694$, $R^2 = 0.41078$. Optimum predicted P-fertilizer rate for “medium” soil P response category was $174.97 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$ or equal to $486.03 \text{ kg SP-36 ha}^{-1}$ (36% P_2O_5). Predicted P-fertilizer recommendation rate based on soil-P response category can be seen in Table 6.

Based on Bray-1 extraction method, under “low” soil response category the regression equation was $RY = -0.00059x^2 + 0.21749x + 63.92204$, $R^2 = 0.23603$. From this regression model, optimum predicted P-fertilizer rate was $184.31 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$ or equal to $511.98 \text{ kg SP-36 ha}^{-1}$ (36% P_2O_5). Under “medium” soil response category the regression equation was $RY = -0.00099x^2 + 0.31956x + 53.69884$, $R^2 = 0.50473$. Optimum predicted P-fertilizer rate for “medium” soil P response category was $161.39 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$ or equal to $448.32 \text{ kg SP-36 ha}^{-1}$ (36% P_2O_5). Although there were differences in soil P category values between Olsen and Bray-1 extraction methods, the predicted P fertilizer recommendation were similar for the same soil P category responses.

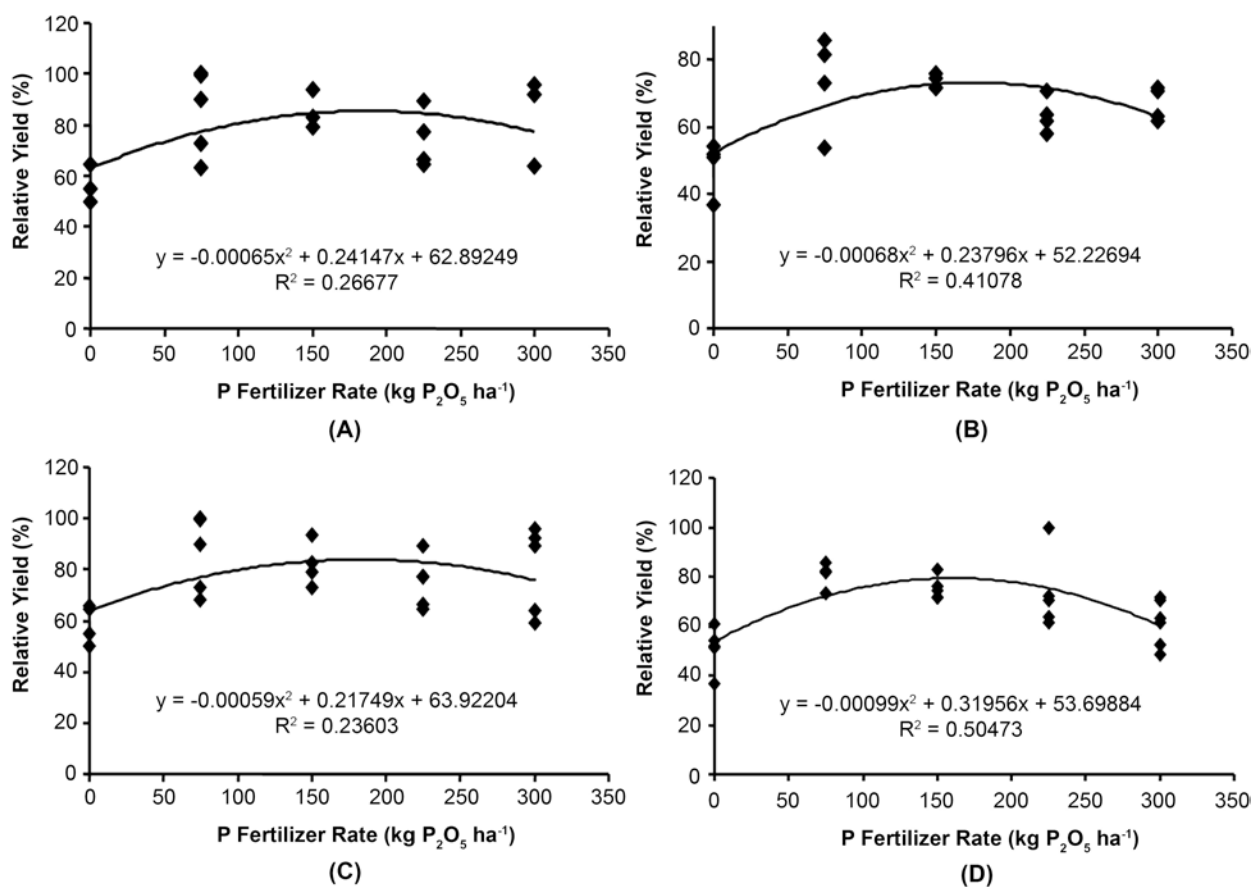


Figure 3. Relationship between P-fertilizer rate and relative yield of yard long bean on Ultisols, Nanggung, Bogor based on response category determined by different extraction methods (A) Low soil-P response category by Olsen (B) Medium soil-P response category by Olsen (C) Low soil-P response category by Bray-1 (D) Medium soil-P response category by Bray-1

Table 5. The Olsen and Bray-1 soil test calibration for yard long bean in Ultisols, Nanggung, Bogor

Response category	Relative yield (%)	Extracted-P (ppm P ₂ O ₅)	
		Olsen	Bray I
Very low	≤ 50	≤ 18.40	-
Low	> 50 - < 75	> 18.40 - < 117.27	≤ 87.81
Medium	> 75 - < 100	> 117.27 - < 267.04	< 87.81 - < 233.78
High	≥ 100	≥ 267.04	≥ 233.78

Table 6. Predicted P-fertilizer recommendation rate for yard long bean in Ultisols, Nanggung, Bogor, based on soil-P response category

Soil-P response category	Predicted P-rate (kg ha ⁻¹)		Regression equation	R ²
	P ₂ O ₅	SP-36		
Olsen				
Low	185.75	515.96	RY = -0.00065x ² + 0.24147x + 62.892	0.26677
Medium	174.97	486.03	RY = -0.00068x ² + 0.23796x + 52.227	0.41078
Bray-1				
Low	184.31	511.98	RY = -0.00059x ² + 0.21749x + 63.922	0.23603
Medium	161.39	448.32	RY = -0.00099x ² + 0.31956x + 53.699	0.50473

CONCLUSION

From this study it can be concluded that Olsen, Bray-1, HCl 25%, and Mechlich-1 soil test can be used to determine soil-P for yard long bean production in Ultisols-Nanggung. The coefficient correlation (r) of extraction reagent Olsen, Bray-1, HCl 25%, and Mechlich-1 were 0.772, 0.765, 0.755, and 0.732, respectively. With the Olsen soil test, Ultisols-Nanggung can be divided into very low, low, medium and high soil response category. However with the Bray-1 soil test they only can be divided into low, medium, and high soil response categories.

ACKNOWLEDGEMENT

This publication was made possible through support provided by the United States Agency for International Development and the generous support of the American People (USAID) for the Sustainable Agriculture and Natural Resources Management Collaborative Research Support Program (SANREM CRSP) under terms of Cooperative Agreement Award No. EPP-A-00-04-00013-00 to the Office of International Research and Development (OIRE) at Virginia Polytechnic Institute and State University (Virginia Tech).

REFERENCES

Al-Jabri, M. 2007. Perkembangan uji tanah dan strategi program uji tanah masa depan di Indonesia. J. Litbang Pertanian 26:54-66.

Chang, J., D.E. Clay, C.G. Carlson, C.L. Reese, S.A. Clay, M.M. Ellsbury. 2004. Defining yield goals and management zones to minimize yield and nitrogen and phosphorus fertilizer recommendation errors. Agron. J. 96:825-831.

Dahnke, W.C., R.A. Olson. 1990. Soil test correlation, calibration, and recommendation. p. 45-57. In R.L. Westerman (Ed.) Soil testing and plant analysis, 3rd ed. SSA No 3. Soil Sci. Soc. Amer. Inc., Madison.

Daniels, M., T. Daniel, K. Van Devender. 2008. Soil Phosphorus Levels: Concerns and Recommendations. The University of Arkansas Cooperative Extension Service. <http://www.uaex.edu>.

Daverede, I.C., A.N. Kravchenko, R.G. Hoeft, E.D. Nafziger, D.G. Bullock, J.J. Warren, L.C. Gonzini. 2003. Phosphorus runoff: effect of tillage and soil phosphorus levels. J. Environ. Qual. 32:1436-1444.

Dobermann, A., T. George, N. Thevs. 2002. Phosphorus fertilizer effects on soil phosphorus pools in acid upland soils. Soil Sci. Soc. Am. J. 66:652-660.

Hochmuth, G.J. 2008. Fertilizer Management for Greenhouse Vegetables-Florida Greenhouse Vegetable Production Handbook, Vol 31. IFAS Extension, University of Florida.

Kasno, A., S. Adiningsih, Sulaiman, Nurjaya, Asmin. 2001. Kalibrasi uji tanah hara P tanah Oxisols, Sulawesi

- Tenggara untuk tanaman jagung. hal. 397-417. *Dalam* Prosiding Seminar Nasional Reorientasi Pendayagunaan Sumberdaya Tanah, iklim, dan Pupuk.
- Kelling, K.A., L.G. Bundy, S.M. Combs, J.B. Peters. 1998. Soil test recommendation for field, vegetable, and fruit crops. Cooperative Extension-University of Wisconsin-Extension.
- Kidder, G., E.A. Hanlon, T.H. Yeager, G.L. Miller. 2003. IFAS Standardized Fertilization Recommendations for Environmental Horticulture Crops1. IFAS Extension, University of Florida.
- Nursyamsi, D., D. Setyorini, I.P.G. Widjaja-Adhi. 1993. Penentuan kelas hara P terekstrak dengan metode analisis keragaman yang dimodifikasi. hal. 217-235. *Dalam* Prosiding Pertemuan Teknis Penelitian Tanah dan Agroklimat Bidang Kesuburan Tanah dan Produktivitas Tanah. Bogor 18-21 Februari 1993.
- Sawyer, J.E., A.P. Mallarino. 1999. Differentiating and understanding the Mehlich 3, Bray, and Olsen soil phosphorus tests. Presented at the 19th Annual Crop Pest Management Short Course, University of Minnesota, November 22, 1999, St. Paul, MN.
- Skogley, E.O. 1994. Reinventing soil testing for the future, p. 187-201. *In* J.L. Havlin, J.S. Jacobsen (Eds.) Soil testing prospects for improving nutrient recommendations. Soil Sci. Soc. Amer. Inc., Madison.